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DETERMINING THE EFFICIENCY OF SPONTANEOUS SOURDOUGH FOR STABILIZING THE QUALITY OF BREAD PRODUCTS IN BAKERIES AND CATERING ENTERPRISES

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Проведено аналіз давніх традицій хлібопечення з огляду вибору стратегії розвитку сучасних підприємств хлібного і ресторанного бізнесу: удосконалення технологій, асортименту і покращення якості хлібних виробів. Значну увагу приділено проблемам, що гальмують впровадження технологій продукції на спонтанних заквасках. Підкреслено актуальність формування теоретичного підґрунтя таких технологій, конкретизації вимог до сировини, напівфабрикатів і продукції, гармонізації прийнятих у світовому хлібопеченні термінології, технологій і нормативної документації.

Обґрунтовано доцільність вивчення автентичних для України пшеничних спонтанних заквасок – хмелевої та на винних дріжджах, а також традиційної для Кавказу горохово-анісової закваски.

Встановлено значний вплив рецептури і характеристик сировини на якість заквасок. Доведено, що завдяки використанню винних дріжджів у розвідному циклі закваска набуває необхідної якості за 1–3 доби. Хмелева закваска для дозрівання потребує 7–8 діб, горохово-анісова – 15 діб. Закваски мають загальні та специфічні ознаки – бродильну здатність і кислотність, особливі органолептичні і біотехнологічні властивості, мікробіологічний склад. Це впливає на перебіг технологічного процесу і потребує коректування параметрів ведення заквасок та приготування хліба на їх основі. Характерними для хліба на спонтанних заквасках є яскраві органолептичні характеристики. Показано здатність заквасок гальмувати черствіння продукції і попереджувати її мікробіологічне псування. Встановлено, що хмелева та горохово-анісова закваски стабільні протягом 90, а закваска на винних дріжджах 30 діб ведення.

Отримані результати дають підстави стверджувати про перспективність використання спонтанних заквасок у хлібному та ресторанному бізнесі. Це може стати підґрунтям для розробки рекомендацій по вирішенню проблем і формуванню продукції високої якості, розширення асортименту на сучасних промислових та крафтових виробництвах

Ключові слова: спонтанні закваски, хмелева закваска, горохово-анісова закваска, винні дріжджі, національний хліб

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1. Introduction

Bakery products and their technology are synonymous with national wealth and well-being for many peoples of the world; they have been fairly called holy and a symbol of life. Moreover, bread and basic concepts about it are one of the points of national identification, an integral part of ethnicity and traditions, which distinguishes the culture of different peoples [1–3]. However, in recent decades the common trend in the United States and the leading EU countries has been to reduce consumption of traditional bakery products [4, 5]. This is due to the quality of products differing from consumer preferences along with the fact that media often calls for restrictions on their consumption or even their removal from the diet. Low nutrient content, high calorie content, and the usage of a wide range of synthetic additives at all stages of production (growing of grain, flour and bread preparation) are used as arguments. Wheat and its products are among the top ten allergens, particularly due to gluten content. Also, high amount of acrylamide, which has carcinogenic properties, is formed during bread preparation. All this raises doubts regarding the safety of bread among consumers and a number of nutritionists, connecting it to a whole spectrum of non-infectious diseases: diabetes, allergies, disorders of various systems of the body [6, 7].

Analysis of the Ukrainian bread market also shows a number of acute problems. According to the statistics, 26 kg of bread is produced by industrial enterprises per each Ukrainian every year, which is much less than the average European citizen consumes (about 50 kg) [8]. There is a tendency to reduce consumption of traditional bread varieties. The imperfection of product range, rapid loss of freshness, faint flavor and aroma, fragile crumb, frequent cases of microbiological damage, and the content of synthetic additives, which are the result of the spread of accelerated technologies, lead to dissatisfaction among Ukrainians [9–11].

Therefore, it is important to analyze the experience of the leading countries in solving the problems of the industry and study the potential of the Ukrainian baking industry regarding the development of measures to increase demand for products. It is important to revive national sourdough technologies by determining the formulas and technologies of sourdoughs as well as bread products based on them. Thus, it is necessary to study the biotechnological properties of various sourdoughs, their effect on the process of dough preparation and the quality and stability of finished products during storage. The development of recommendations for adapting such technologies to the working conditions of modern bakeries and factories is relevant. This may become the basis for choosing a modern development strategy for domestic bread making, solving the problems, improving the range and quality of bakery products.

2. Literature review and problem statement

Today, the European bakery sector consists of more than 190,000 small and medium enterprises and 2,200 large companies with more than 2 million people. The mini-bakeries and craft bakeries are considered a significant source of diverse workplaces in the world. At the same time, 54 % of European businesses employ fewer than 20 people, and in the US, the average bakery has about 35 people (smaller commercial mini-bakeries with 2–4 employees make up almost a quarter of all establishments) [12].

The so-called "premium class" products are particularly popular. They are manufactured according to the old (authentic), traditional for this territory or borrowed from other cultures technologies, using different spontaneous sourdoughs, manual labor, and wood and stone ovens. According to industry experts [13], the bread market in Ukraine will preserve the importance of powerful industrial bakeries, primarily as a guarantee of stable production of high-quality and affordable traditional staple bread products. But mini-bakeries, which mostly combine the functions of production and sale through shops, restaurants, and cafes, will develop more actively, as they do in Europe.

As for the product range of the Ukrainian market, an overview of current scientific papers [9–11, 13], as well as promotional articles [14–18] on the websites of bakery enterprises gives grounds to state that the same tendencies are observed. Interest of consumers, scientists, and bread production specialists grows towards bread that does not contain industrial yeast and synthetic chemical additives and is prepared only with natural raw materials and various sourdoughs. "Live bread", made from rye-hop leaven with the addition of flax, mashed potatoes, paprika and other spices [14], is popular in the Poltava region, as is "Buckwheat hop bread" [15]. Hop sourdough bread without yeast is offered in Nizhyn [16, 17] and Kozyatin: the "Healthy Food" line [18]. In this case, the producers are interested in implementing the bread technology of other traditional Ukrainian and ethnic (Bavarian, Caucasian, Belarussian, etc.) sourdoughs, referring to the experience of different peoples of the world [14–18]. Demand for ethnic and exotic breads in restaurants, fashionable cafe-bakeries, elite bakeries, and other snack bars is growing. High-quality restaurants report that nearly 32 % of revenues include a separate order for bread (much more than an average of 12.5 % for restaurants as a whole) [19–21].

Moreover, in the opinion of scientists and producers, it is only possible to obtain quality bread while using sourdough, especially when following popular world trends:

– "For Health" with whole rye, wheat [22, 23], or spelt flour, or flour from other cereals [24], with improved nutritional value, carbohydrate composition [25], absorption of biologically active substances;

– "Low Allergen / Allergen Free" with improved gluten or gluten-free [26];

– safe, with reduced acrylamide content [27, 28], with "Clean Label" or "Organic" [29].

Also, sourdough is required to form the special characteristics of ethnic products, enhance the bread flavor and aroma in traditional products [30, 31], provide longer shelf-life and microbiological stability, along with improved functional characteristics [29, 32–37]. It can become an alternative to synthetic enhancers in order to solve the problems of the baking industry [29, 32].

Thus, in [32], sourdough is considered as a means of improving the quality of the product and its stability during storage and improving physiological properties: reducing the glycemic index of products and destroying allergens (particularly, gluten). The authors [33] also indicate the potential of sourdough to increase the bioavailability of minerals and synthesis of biologically active compounds, and improve metabolism. The paper [34] noted the effectiveness of using sourdough in order to prolong the shelf-life of bakery products due to the inhibitory activity of lactic acid bacteria against microbiological pathogens. In this case, as shown in [35], any changes in the formulation and parameters of sourdough have a significant effect on both their technological and microbiological characteristics. This may allow the cultivation of sourdough with a required species composition of the microflora [36]. In [37], the use of sourdough in the fermentation phase of dough preparation with the inclusion of hop extract was proposed. This technology includes the stages of flour gelatinization and its fermentation by commercial strains of lactic acid bacteria and yeast with subsequent dough preparation. Improved quality and stability of the resulting products during storage are proven.

However, the recommendations for their implementation in the aforementioned studies do not exclude commercial yeast, pure cultures of microorganisms, and other ingredients from the formulations, and for the most part an intensive method of dough preparation is used. Therefore, proposed technologies can not be fully positioned as "revived ancient, national, ethnic", which are based on using spontaneous sourdough and prolonged dough preparation, minimization of intense mechanical effects, etc. Bakery products obtained by such approaches are highly appreciated by consumers and can take a niche of "premium-class" products.

The authors [38–42] use spontaneous sourdough, but the analysis of these works showed different approaches in preparing sourdough and products based on it. These results confirmed that the properties of sourdough and the species composition of the microflora can vary significantly depending on the raw materials used, region of their origin, formulation, propagation parameters, and climatic conditions both during dilution and production cycles. Thus, in the paper [38] examples of different preparation technologies of sourdoughs are presented and the quality of bread products based on them are investigated. However, the authors did not establish a clear connection between the properties of sourdoughs and the parameters of their propagation. The work [39] analyzes the physical, chemical, and microbiological properties of sourdoughs produced using various types of flour, but there is no information on the possible effects of additional ingredients. The authors [40] studied the composition of the nutrient medium used for sourdough fermentation and its technological properties in more detail. The study of sourdoughs with additional ingredients, particularly, hop extract, is presented in [41] and [42]. However, the issues of predictability and stability of sourdough properties, the course of technological process and quality of finished products, patterns of their changes under the influence of basic factors remain unsolved. Development of technological instructions for spontaneous bread sourdough production is necessary. It is relevant to formulate clear requirements for the quality of raw materials, semi-finished and finished products at all stages of long-term, multi-stage technology, as well as to develop recommendations for using effective control methods.

Theories about genetic proximity to products made from local raw materials and by traditional technologies and the priority of using the potential of Ukrainian baking makes reviving authentic Ukrainian bread technologies a promising direction. These include bread technology with spontaneous hop and wine yeast sourdough. Additionally, the popularity of Caucasian bakery products in Ukraine indicates the expediency of studying pea-anise sourdough used for making "shirmay-non". It is necessary to establish the parameters of its propagation and the possibility of implementing it in the manufacture of wheat bread using local raw materials.

Therefore, it is advisable to carry out research aimed at the revival of bakery technologies based on using the above-mentioned sourdoughs, and to develop recommendations for their adaptation to the current production conditions and quality of raw materials.

3. The aim and objectives of the study

The aim of this study is to determine the technological features and quality of selected sourdoughs and sourdough bread in order to revive and implement an old range of products with improved quality.

In order to achieve this goal, the following objectives were set:

– to determine the biotechnological properties of spontaneous wheat sourdough based on pea-anise extract, hop extract, and wine yeast in the dilution and production cycles and establish the possibility of their propagation for a prolonged time;

– to evaluate the effect of sourdough on the course of biochemical and microbiological processes during the preparation of wheat dough with complete elimination of yeast from the formulation;

– to analyze the quality of wheat sourdough bread and the influence of the chosen method of dough preparation on the speed of its staling and resistance to microbiological damage;

– to develop recommendations regarding the directions and methods of using sourdough and identify the problems and ways to solve them for the practical realization of spontaneous sourdough bread technology, adapted to raw materials and conditions of production at enterprises of different capacities.

4. Materials and methods of investigating the properties of spontaneous sourdough and sourdough bread

4. 1. Studied objects and materials

Two samples of TM "Bohumila" (Ukraine) wheat flour were used for sourdough and bread production: sample 1 was 1st grade flour; sample 2 was high grade flour. Flour quality characteristics are presented in [43].

Other basic and additional raw materials that met the requirements of the relevant regulations were used: food-grade salt (DSTU 3583-97); table sugar (DSTU 4623:2006); sunflower oil (DSTU 4492:2005); non-fermented malt from Zhytomyr distillery (DSTU 4282:2004); peas (DSTU 4523:2006); type 90 "UA-AROMA" fine aromatic grade granulated hop (DSTU 4099-02) from the scientific-industrial enterprise "WESTHOPS" (city of Brody, Ukraine); anise (GOST 18315-78).

Samples of spontaneous wheat sourdough were prepared in three variations:

1) pea and anise sourdough, made from pea-anise extract according to [44];

2) hop sourdough, the parameters of which were established in [29];

3) sourdough made using dried wine yeast in the dilution cycle, as described in [45].

More detailed features of dilution and production cycles of sourdough preparation, influential input factors, list of controlled parameters and estimated quality characteristics of semi-finished products are described in [43]. During the dilution phase, nutritional mixture was used for replenishment for several cycles until the required volume of sourdough was reached with required lifting force, acidity, microflora composition, and sensory characteristics. In the production cycle, part of ripe sourdough (50–75 %) was removed and used to prepare the dough. A nutrient mixture was added to the rest; its main ingredients were wheat flour and water, after which the mixture was left for ripening, acquiring the necessary biotechnological properties.

4. 2. Methods of studying the quality of semi-finished and finished products

During the study, the bread was prepared in 3 ways: with straight dough, thick sponge, and liquid sponge. Sourdough was introduced in the amount of 30 % to the total mass of flour; yeast was present only in the formulation of the control sample.

The control sample was made by test baking method according to GOST 27669-88 and recommendations [46].

When preparing samples of straight dough, all raw materials and sourdough were introduced in one stage. The total duration of dough fermentation at 28–30 °C was determined by the specified sensory properties, lifting force, and acidity.

The thick sponge was prepared with 50 % of the total amount of flour used for dough preparation, sourdough, and the calculated amount of water. Moisture content was 45–50 %. The liquid sponge was prepared similarly, using 28 % of flour, sourdough, and the amount of water needed to reach the moisture content of 68–70 %. The fermentation time of the sponges at 28–30 °C was determined by the necessary sensory characteristics and the above-mentioned biotechnological properties. The dough was mixed in the Brabender farinograph where the remaining flour and water, sponge, saline solution, and sunflower oil were added (the dough consistency was 500 device units). Every hour the dough was kneaded, and after reaching the necessary acidity and lifting force, it was manually shaped and proofed. The duration of proofing in the thermostat at (38±2) °C and relative humidity (78±2) % was determined by the volume and shape of the loaves. They were baked in a box oven at 220–240 °C.

The quality of semi-finished products (sourdough, sponge, and dough) was monitored by moisture content, acidity, and lifting force. Microflora composition of raw materials and sourdough was determined by microscopy, direct counting, seeding on the selective medium and counting the colonies. The methods are described in more detail in [43].

The structural and mechanical properties and the amount of water needed to obtain a dough of a given consistency were studied using the "Brabender" farinograph.

The quality of bread was evaluated by physico-chemical (specific volume and shape stability of the products, structural and mechanical properties of the crumb) and sensory properties (appearance, surface condition of the crust, porosity structure, taste, smell). The duration of freshness preservation was studied by the change in structural and mechanical properties of the crumb during 48 hours of storage. The changes of its total, elastic, and plastic deformation were determined on the penetrometer AP 4/1 (Germany) [45]. The degree of staling was also studied by the crumbling of bread crumb, determining the percentage of crumbs formed during shaking [47].

The microbiological parameters of bread, particularly the presence of hay bacillus and mold were determined by thermostating the finished products wrapped in wet paper at 37 °C for 36–72 hours or until the first signs of deterioration [48, 49].

The results of experimental studies were presented in the form of graphs. They were also subjected to statistical processing, implemented with standard Microsoft Office software packages.

5. Results of studying the quality of spontaneous wheat sourdough and semi-finished and finished products based on it

The purpose of spontaneous wheat sourdough is the accumulation of fermentative microflora, which will ensure dough rising, the production of organic acids, flavor, aromatic, and other technologically meaningful compounds. The processes taking place during sourdough ripening also ensure the transformation of ingredients and the formation of consumer properties, nutritional value, and improve adsorption of nutritional and biologically active compounds of bakery products. At the same time, preparing spontaneous sourdough with the necessary biotechnological properties is a complex task since they depend on numerous factors [43]. Primarily, the quality of flour and that of possible additional ingredients affects the development and activity of yeast and lactic acid bacteria, which ensure the formation of high-quality bread and suppression of extraneous microorganisms that can change the normal course of fermentation and reduce the quality of products [50].

However, the baking properties of raw materials are not stable and the sourdough formulations are extremely diverse, so their biotechnological properties can fluctuate within wide limits. Accordingly, changes in the quality of products can be positive (the formation of special, characteristic only for this type of products taste, aroma, and appearance), as well as negative (product defects). Organizing the sourdough bread production and choosing the method of dough preparation require an individual approach, taking into account their formulations, and constant adjustment of the parameters of the technological process for leveling fluctuations in the quality of raw materials. This, along with the lack of proper regulatory and technical base, complicates the use of spontaneous sourdough in industrial baking conditions, where the intensity of the process and the stability of product quality are the priority. But for mini-enterprises, artisan, and "craft" bakeries, such technologies can become the main competitive advantage in the struggle for the consumer.

5. 1. Property features of spontaneous wheat sourdoughs in dilution and production cycles

In this study, sourdough was made using hop extract (sample 1), pea-anise extract (2), and wine yeast (3), as well as only water and flour (4). In [43], the effect of flour quality on the formation of sourdough properties in the dilution cycle, their stability in the production and, accordingly, their ability to ensure the preparation of products of proper quality was studied. First grade wheat flour (a) with too high mold fungi content and general microbial contamination and high grade wheat flour (b) that met the requirements of SNiP regulations [51] were used.

The basic stages and parameters of preparing spontaneous sourdough and the effect of chemical, microbiological composition, baking properties of used flour, as well as the inclusion of additional ingredients on their quality, have been established [43]. Namely, the effect of additional ingredients on the formation and quality of sourdough: water hop extract enriching the nutrient medium with a number of biostimulants and carrying the compounds with selective antiseptic properties; pea-anise extract carrying additional microflora, antiseptic compounds, scarce nutrients, and biologically active substances; and dried wine yeast carrying nutrients and fermentation microflora. The expediency of implementing an additional stage of preparing a nutrient medium in wine yeast sourdough technology has been proven. Gelatinizing and saccharifying the water-flour mixture with white malt enzymes allows to make its composition closer to wine wort, which turns into wine as a result of primarily yeast activity.

The recommended parameters of spontaneous wheat sourdough preparation using first (a) and high (b) grade flour and their quality characteristics in dilution and production cycles [43] are presented in Table 1.

The expediency of using 1st grade flour for sourdough preparation has been established. It has been demonstrated that wine yeast sourdough acquires the necessary properties in one cycle (24 hours), provided that saccharified gelatinized flour is used as a nutrient mixture. Hop sourdough requires 7–8 cycles of replenishment, i. e. 7–8 days. Pea-anise sourdough requires up to 15 replenishment cycles for ripening.

The technological properties of sourdough and its fermentation ability are primarily affected by quantity and specific composition of microorganisms (Table 2).

Table 1

Technological features and quality characteristics of spontaneous wheat sourdough

Parameters and quality characteristics	Sample 1 (hop)		Sample 2 (pea-anise)		Sample 3 (wine yeast)		Sample 4 (without enrichers)	
	a	b	a	b	a	b	a	b
Dilution cycle								
Moisture content, %	69–72							
Starting temperature, °C	29–32							
Nutrient medium (NM) to ripe sourdough (RS) ratio	1 : 1	1 : 1	1 : 1	1 : 1	1 : 1	1 : 1	1 : 1	1 : 1
Single phase duration, hours	24	24	24	24	24	24	24	24
Cycle duration, days	7–8	11	15	15	1	2	9	9
Lifting force, min	26–30	28	24	28	25	29	29	35
Final titrated acidity, °	8.8	8.2	10.1	7.8	7.2	7.9	14.5	11.6
Production cycle								
NM to RS ratio	3 : 1	3 : 1	3 : 1	3 : 1	3 : 1	3 : 1	3 : 1	3 : 1
Fermentation time, hours	24	24	24	24	24	24	24	24
Stability, days	90	90	90	90	30	30	9	9
Lifting force, min	28	27	22	24	24	29	29	35
Final titrated acidity, °	10.3	8.4	11.2	7.6	10.2	9.4	14.2	10.5

Note: [yellow] – *low quality;* [red] – *loss of technological properties*

Analysis of sourdough microbiological parameters confirms the significant effect of flour grade on the formation of biotechnological properties as well as the inclusion of additional ingredients that enrich the nutrient medium, add their own microflora, and contain or stimulate the production of antiseptic compounds. The number of yeast cells in enriched 1st grade flour sourdough is 160–320 million per gram; in high grade flour sourdough it is 39–81 million per gram, in control it is 39 and 15 million per gram, respectively. To compare, the amount of yeast cells should be at least 100 million per gram in liquid yeast with high fermentation capacity [48].

The ratio of yeast and LAB in the studied samples varies from 1:0.3 for samples with wine yeast to 1:3.7 for pea-anise sourdough, and 1:4.4–19.3 for control. In liquid yeast prepared according to the traditional technology this ratio is ≈1:1 [48].

The LAB activity in 1st grade flour sourdough is better than in samples with high grade flour. Lactic fermentation is extremely important in spontaneous sourdough technology. The technological significance of lactic acid and other produced compounds is to create conditions for positive changes in flour biopolymers and a favorable environment for the development of yeast and suppression of extraneous microflora. Additionally, the antiseptic properties of hop and other constituents of sourdoughs, which the fermentative microorganisms are more resistant to, are intensified in acidic medium.

Lower quality and possible problems with the course of lactic acid fermentation are discovered in sourdough with wine yeast. Comparison with control points to the ability of the hop and pea-anise extracts to regulate the development of LAB. In corresponding samples, acid accumulation somewhat slows down on reaching 9–9.5°, probably due to their antiseptic properties strengthening with the same intensity of yeast cell reproduction. This can be used as a stabilizing factor for the sourdough quality and a way to prevent over-acidification, especially in summer.

The ability of hop and pea-anise sourdough to control the development of fermentative microflora is proven by the relative stability of technological properties during their propagation for 90 days. The duration of wine yeast sourdough propagation in the production cycle should not exceed 30 days.

It should be noted that in the control sample of sourdough, which was prepared and propagated using only flour and water, the fermentation ability rapidly decreased and titratable acidity increased. Particularly, these properties changed when using 1st grade flour with increased microbiological contamination. Most likely, with acidity increasing above 12°, only acid-resistant strains, *S. minor* in particular, can remain active, which leads to slower alcohol fermentation.

Microbiological studies of sourdough were carried out at the end of the dilution cycle and every 15 days of production cycle by seeding on solid media using the Koch method. It has been confirmed that bacilli and yeast microorganisms *S. cerevisiae* and *S. minor* were dominant in the studied samples, while extraneous microflora colonies were not found. Microscopy of liquid sourdough revealed that yeast microflora is represented by both adult and budding cells with glycogen content (Fig. 1).

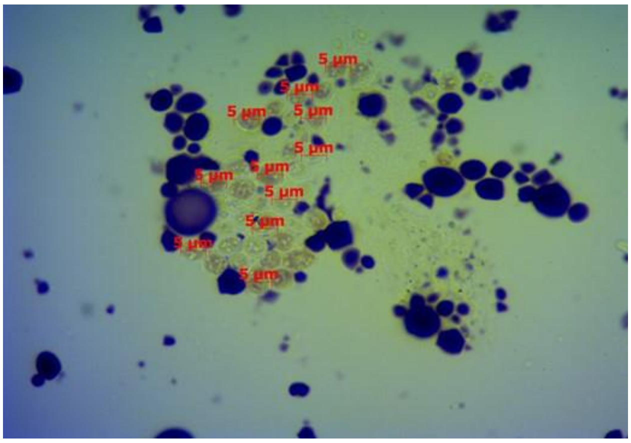
Overall, the obtained results prove that hop and pea-anise sourdough technology has more rationally selected recipes and propagation parameters. Thus, the conditions in dilution and production cycles better correspond to the needs of fermentative microflora regarding the balance of the nutrient medium, physical and chemical conditions, and selective antiseptic activity. This contributes to the breeding of yeast and LAB, maintaining their optimal ratio, and faster suppression of the extraneous microflora, competition with which begins after each replenishment of the water-flour mass. Semi-finished products with wine yeast quickly acquire fermentation ability (24 hours) and remain stable for a shorter period (30 days). This behavior could be due to the peculiarities of species composition and technological properties of the latter, which is more typical for winemaking. Since the dried wine yeast that was introduced as a carrier of fermentative microflora during the first mixing of the dilution cycle was obtained by mixing

Table 2

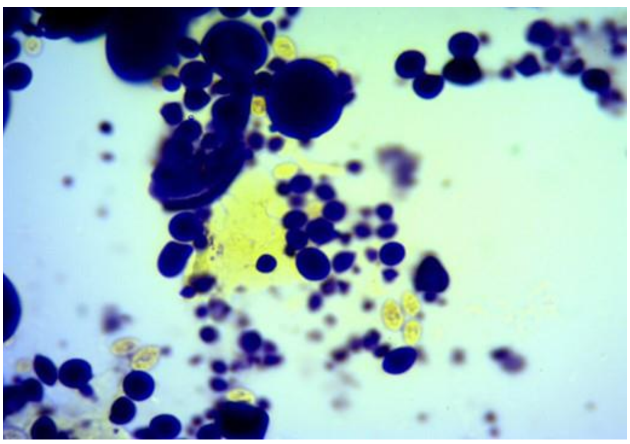
Microbiological characteristics of spontaneous liquid wheat sourdough made from first (a) and high (b) grade flour after the dilution cycle

Properties	Hop		Pea-anise		Wine yeast		Without enrichers	
	a	*b*	*a*	*b*	*a*	*b*	*a*	*b*
Yeast cell content, CFU/g	2.1×10^8	3.9×10^7	1.6×10^8	5.5×10^7	3.2×10^8	8.1×10^7	3.9×10^7	1.5×10^7
LAB content, CFU/g	2.4×10^8	7.3×10^7	3.6×10^8	8.1×10^7	9.6×10^7	4.5×10^7	5.6×10^8	2.9×10^8
LAB activity, min	55	110	45	89	70	136	34	48

the corn flour with the foam of young wine, its microflora is adapted to it.



a



b

Fig. 1. Microphotographs of spontaneous wheat sourdough on the 30th day of propagation; the granulose content of yeast cells: *a* — hop sourdough; *b* — pea-anise sourdough

5. 2. Effect of sourdough on the processes of wheat dough preparation

Long technological process of sourdough propagation, additional ingredients, spontaneous microflora activity, and high acidity can significantly affect the state of proteins, starch, and liquid phase in the dough, and change the course of biochemical processes. These factors will determine variations in the behavior of the dough during mixing. Therefore, it is important to find out the effects of various spontaneous sourdoughs in the amount of 30 % to the mass of flour on the structural and mechanical properties of the dough during its mixing in the Brabender farinograph. The results of the studies are presented in Table 3.

It has been established that adding 30 % of studied sourdough during dough mixing slightly increases the water absorption capacity, which is consistent with long fermentation of sourdough and creating favorable conditions for swelling of proteins and starch. In samples with hop sourdough, the stability is sufficiently long, as is in the control, but dough dilution decreases. This could be due to decreased activity of proteolytic enzymes under the influence of active substances of hop, primarily polyphenols. Some decrease of dough elasticity is also due to the previously established [49] strengthening effect of hop on the gluten frame that reduces its tensile strength by increasing the number of intermolecular interactions. When mixing the dough with pea-anise sourdough, an increase in water absorption and elasticity during the first 10–13 minutes of mixing is observed along with a decrease in stability and increased dilution. This is, apparently, due to the swelling of gluten proteins and interactions with protein substances and other components of peas during sourdough ripening. During dough formation, this may be due to the formation of a gluten film frame, which, due to higher elasticity, more fully covers the starch and binds the liquid phase and other components of the system. However, after a certain moment, this leads to excessive stretching and straining of gluten films in the dough frame, which collapses under the influence of mechanical stress, releasing the liquid phase, which is accompanied by increased dilution. In samples of dough with wine yeast sourdough, similar changes in behavior with increased dilution were recorded, apparently, due to increased activity of proteolytic enzymes and increased adherence of gluten proteins to them. Additionally, each sourdough due to the specificity of spontaneous microflora also has its own peculiarities in the nature of proteolytic enzymes.

Table 3

Structural and mechanical properties of dough, determined using farinograph

Properties	Control without sourdough	Samples with sourdough		
		hop	pea-anise	wine yeast
Consistency, device units	500	500	500	500
Water absorption capacity, cm^3/100 g	60.2	61.1	61.4	60.8
Formation time, min	5.0	4.0	4.5	4.5
Stability, min	10.0	11.0	8.5	9.5
Elasticity, device units	100	90	110	100
Dilution, device units	80	60	100	110

Literary sources, most of which are popular science, contain ambiguous information about recommended methods and dough preparation parameters using spontaneous sourdough. No instructions were found regarding their adaptation to the specific features of local raw materials and production conditions. Therefore, in this work it was necessary to compare and choose a more rational way of dough preparation and determine the required duration of the process for the studied sourdoughs. The dough was prepared in a straight manner, and with thick and liquid sponges, using samples prepared according to the traditional yeast bread technology as control. It is commonly assumed that the sponge is ready if it achieves the standard technological parameters of acidity and sensory properties. However, the use of wheat sourdough with high acidity (Table 4), the exclusion of pressed yeast from the formulations, and the lack of technological instructions necessitates the evaluation of the course of both lactic acid and alcoholic fermentation processes. Therefore, the maturity of the sponges, the readiness of the dough, and the required length of each stage were judged by the change in lifting force and titrated acidity. Graphic interpretation of results is presented in Fig. 2, 3.

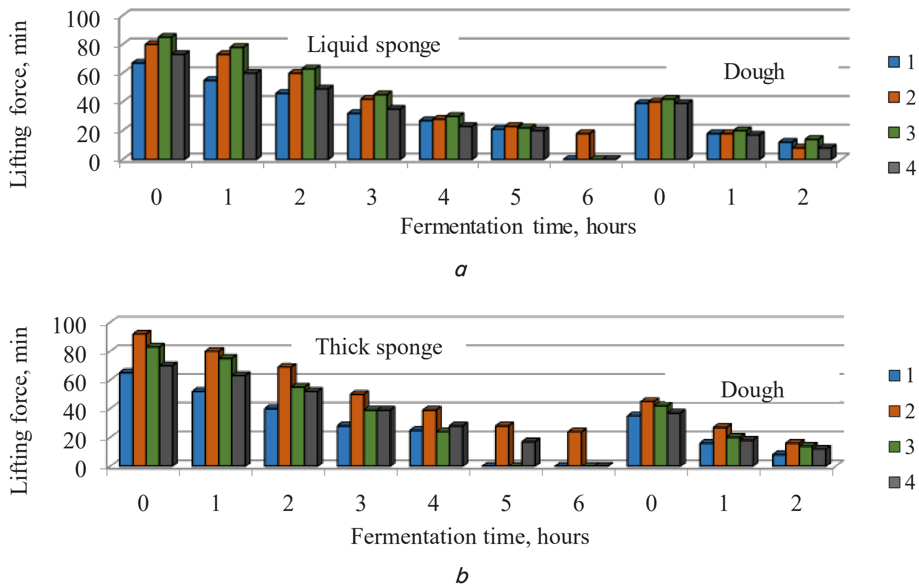


Fig. 2. Changes in fermentation activity of sponges and dough during their ripening: *a* – liquid sponge; *b* – thick sponge; 1 – control sample with 1 % of pressed yeast; 2 – sourdough with hop extract; 3 – sourdough with pea-anise extract; 4 – sourdough with wine yeast

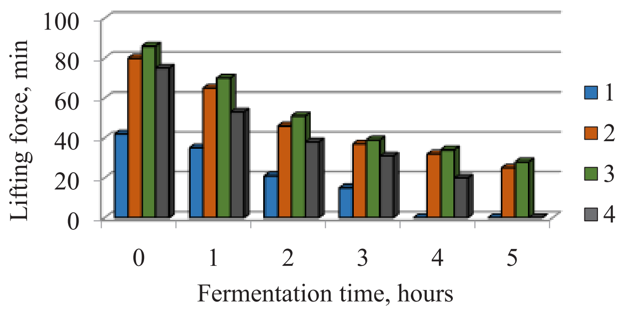


Fig. 3. Changes in fermentation activity of dough during its ripening: 1 – control sample with 1 % of pressed yeast; 2 – sourdough with hop extract; 3 – sourdough with pea-anise extract; 4 – sourdough with wine yeast

There is evidence that the lifting force of ripe sponge should be within 17–25 minutes and it should be within 10–15 minutes for the dough. The titrated acidity of thick sponge made from 1st grade flour should be 3.5–4.0° and it should be 5.0–6.5° for liquid sponge.

It has been established that it is advisable to use straight dough for samples with wine yeast sourdough, and the fermentation time should be at least 4 hours, which is one hour more than the control. It is recommended to use sponge, primarily liquid, for dough with hop and pea-anise sourdough. The intensity of ripening processes in samples with sourdough after 3.5–4.0 hours of fermentation was almost the same as in control. The ripening time of the liquid sponge with hop sourdough should be within the range of 5–6 hours; it should be up to 5 hours for control, pea-anise, and wine yeast sourdough. Dough with sourdough had practically the same fermentation activity as control and acquired the necessary properties in 1.0–2.0 hours.

Dough made with thick sponge had consistently lower intensity of alcohol fermentation than control throughout the study. Samples with pea-anise sourdough were closer to control; samples with wine yeast were the opposite. The recommended duration of sponge ripening is 4 hours for the former and 5 hours for the latter; up to 2 hours for the dough. The ripening of thick sponge with hop sourdough occurs more slowly, which is probably due to the higher concentration of hop active substances in the liquid phase, which slows the development and fermentation activity of yeast.

5. 3. Changes in bread quality and stability during storage due to the influence of spontaneous sourdough

The parameters of the technological process (Table 4) were selected taking into account the obtained data and test baking was made with a comparative assessment of the quality of semi-finished products and bread. The dough was prepared with liquid sponge (LS), thick sponge (TS), and straight dough (SD). For the control sample, pressed yeast was introduced in an amount of 1 % (sponge) or 3 % (straight dough) to the weight of flour.

Photos of finished products are presented in Fig. 4.

The results of test baking have shown that samples with spontaneous sourdough had a pleasant aroma with flavors specific to the corresponding sourdough, darker crust, bright color, sufficient volume and crumb softness. The nature of porosity was somewhat different, particularly samples with pea-anise sourdough had uneven porosity with large pores, which is unusual for the traditional range of products, but is typical, for example, for baguettes. Despite some differences in the technological properties of sponges and dough (Fig. 2, 3) prepared by different methods, the products had good sensory properties (Fig. 4).

The results of assessing physical and chemical properties of finished products are presented in Table 5.

However, liquid sponge products with sourdough had the best sensory, physical, and chemical parameters. The porosity and specific volume of sourdough bread were comparable to the control sample made with the traditional liquid sponge. However, there was a 0.6–1.5° increase in titrated acidity that is slightly higher than the normalized values for traditional bread made from 1st grade wheat flour. This should be adjusted in the regulatory documents for spontaneous sourdough bread products.

The strengthening influence of hop sourdough on the structural and mechanical properties of dough masses throughout the technological process was confirmed, since the shape stability of these products was too high. Dough with pea-anise and wine yeast sourdough has a greater tendency to dilution, which is established using the farinograph (Table 3). However, the loaves of the corresponding samples were easy to process and had the necessary shape retention and gas retention capacities, as evidenced by porosity, volume, and uniformity of finished products.

Table 4

Parameters of technological process and properties of semi-finished products

Parameters	Control			With sourdough								
				hop			pea-anise			wine yeast		
	LS	TS	SD	LS	TS	SD	LS	TS	SD	LS	TS	SD
Sponge preparation												
Moisture content, %	70	50	–	69	50	–	70	49	–	68	47	–
Fermentation time, min	240	240	–	360	360	–	300	240	–	300	240	–
Lifting force, min	24	21	–	17	22	–	20	20	–	18	21	–
Final titrated acidity, °	5.0	3.5	–	6.4	6.6	–	6.8	7.1	–	5.5	5.9	–
Dough preparation												
Moisture content, %	44.0	44.2	43.6	44.4	44.4	43.9	44.5	44.1	43.8	44.1	43.8	43.5
Fermentation time, min	60	60	180	90	120	300	90	90	300	90	90	240
Lifting force, min	16	14	13	9	13	20	12	12	22	7	11	18
Final titrated acidity, °	3.8	3.5	3.1	4.4	5.2	3.9	5.6	6.2	6.5	3.9	4.3	4.2

Table 5

Physical and chemical properties of wheat bread with yeast and spontaneous sourdough

Parameters	Control			With sourdough								
				hop			pea-anise			wine yeast		
	LS	TS	SD	LS	TS	SD	LS	TS	SD	LS	TS	SD
Moisture content, %	43.2	43.3	42.9	43.5	43.3	43.0	43.8	43.4	42.9	43.0	42.8	42.7
Acidity, °	2.9	2.7	2.2	3.5	3.7	3.0	4.4	5.0	5.3	3.0	3.2	3.1
Porosity, %	73	72	69	72	69	65	74	72	71	73	71	68
Specific volume, $cm^3/100$ g	3.17	3.06	2.95	3.12	2.91	2.74	3.23	3.12	3.10	3.20	3.09	2.85
Shape stability, H/D	0.58	0.56	0.56	0.65	0.71	0.64	0.61	0.62	0.64	0.50	0.49	0.47

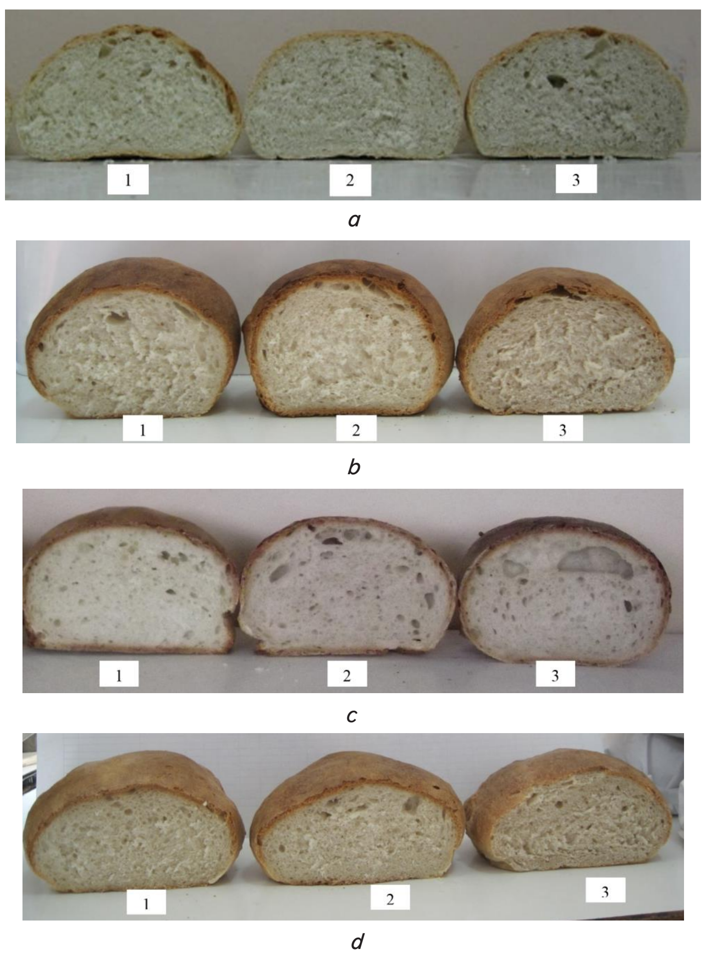


Fig. 4. Photos of bread made from 1st grade wheat flour: *a* — with pressed yeast (control); *b* — with hop sourdough; *c* — with pea-anise sourdough; *d* — with wine yeast sourdough; 1 — liquid sponge; 2 — thick sponge; 3 — straight dough

One of the most acute modern quality problems of traditional bakery products is their rapid staling, accompanied primarily by the loss of bright bread flavor and aroma, crumb elasticity, and increased crumbling. Sourdough bread technologies with long fermentation time should be effective in solving these problems. The changes in structural and mechanical properties of bread crumb during 48 hours of storage were studied using the AP-4/1 penetrometer. Its elasticity was judged by general deformation; elastic deformation was also informative since it shows the ability of the crumb to restore its shape after removing the load. The fresher the bread, the higher its parameters of general and elastic deformation are (Fig. 5).

The study has shown a significant improvement in the crumb elasticity of sourdough bread made with liquid and thick sponges by 13.9–24.3 % and 14.2–25.0 %, respectively; 30.5–37.9 % for straight dough. The staling process was slower in bread with hop, pea-anise, and wine yeast sourdough than in control samples. After two days of storage, the general deformation of crumb decreased by 32.6, 30.8, and 32.8 %, respectively, in bread made with liquid sponge, while in control this value was 42.6 %. When using thick sponge, the total deformation decreased by 27.4, 27.9, and 35.1 %, respectively, and by 35.7 % in control. Samples made by straight dough method with sourdough lost 38.6, 38.2, and 47.6 % of freshness after two days of storage, and control sample lost 51.6 %. But the numerical value of the total deformation in samples with hop, pea-anise, and wine yeast sourdough after this storage period exceeded the corresponding control sample. For liquid sponge samples, the difference was 43.9, 50.0, and 33.3 %; for thick sponge it was 36.1, 40.3, and 15.3 %; for straight dough it was 69.5, 76.1, and 41.3 %. Slower rate of freshness loss in samples with sourdough is also demonstrated by the elastic deformation of bread crumb.

Changes in crumbling of bread crumb during storage have also been determined (Fig. 6).

The obtained results correlate with the penetrometer data and confirm slower bread staling when using sourdough. Deeper colloidal and biochemical processes occurring with biopolymers of flour systems during prolonged dough preparation when using sourdough provide them with more complete transformations during baking. This has a positive effect on the crumb elasticity and slows the aging process of gelatinized starch and denatured proteins.

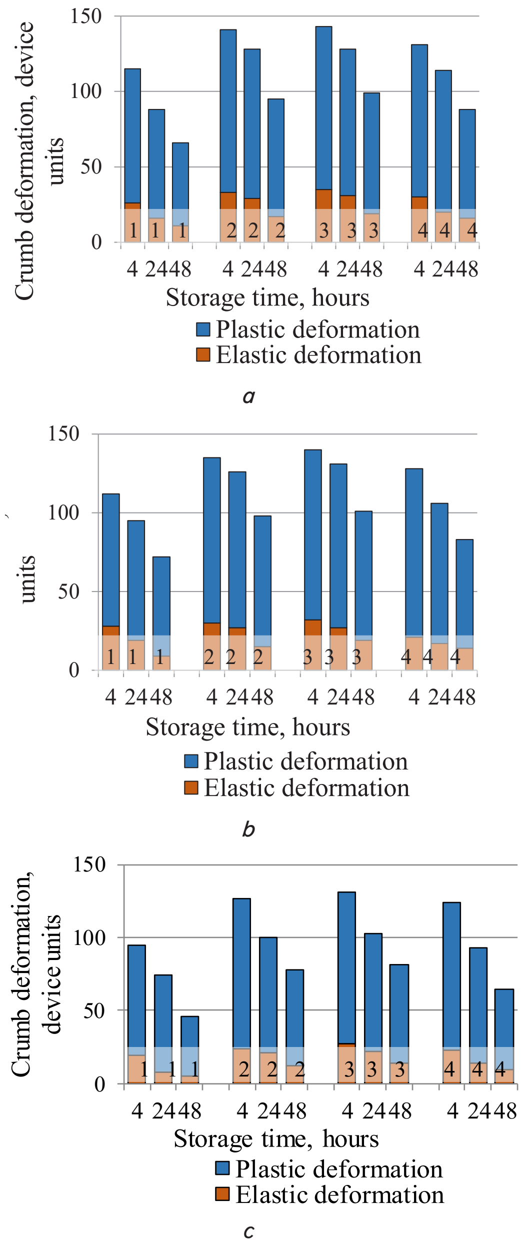


Fig. 5. Changes in crumb deformation during 4, 24, and 48 hours of storage: *a* – liquid sponge; *b* – thick sponge; *c* – straight dough; 1 – with pressed yeast (control); 2 – with hop sourdough; 3 – with pea-anise sourdough; 4 – with wine yeast sourdough

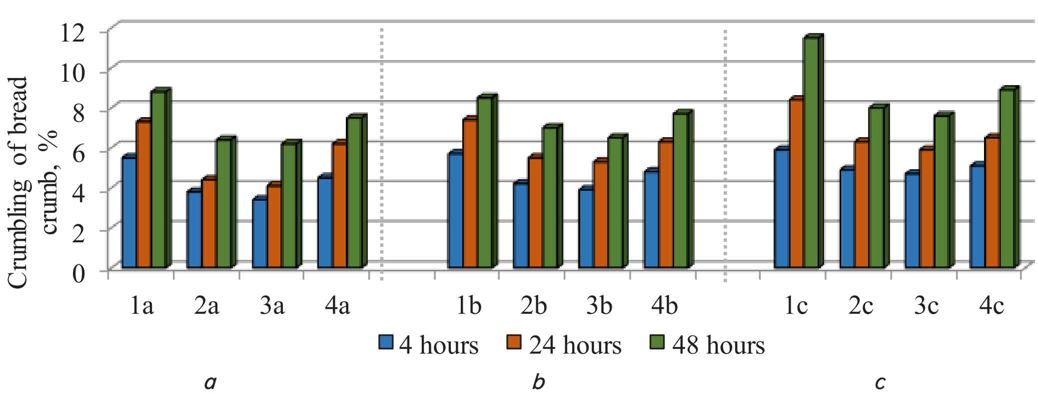


Fig. 6. Changes in crumbling of bread crumb: *a* – liquid sponge; *b* – thick sponge; *c* – straight dough; 1 – with pressed yeast (control); 2 – with hop sourdough; 3 – with pea-anise sourdough; 4 – with wine yeast sourdough

To test the effect of spontaneous sourdough on bread stability towards microbiological damage, especially given the increased contamination of 1st grade wheat flour, its baked samples were examined. These samples were packed in polyethylene bags and stored in provocative conditions until signs of hay bacillus growth or visible mycelium of mold were detected organoleptically (Table 6).

Table 6

Microbiological state of wheat bread during storage

Signs of microbiological spoilage	Control			With sourdough								
				hop			pea-anise			wine yeast		
	LS	TS	SD	LS	TS	SD	LS	TS	SD	LS	TS	SD
Hay bacillus:												
after 24 hours	–	–	–	–	–	–	–	–	–	–	–	–
after 48 hours	–	–	+	–	–	–	–	–	–	–	–	–
after 72 hours	–	+	+	–	–	–	–	–	–	–	–	+
Mold:												
after 24 hours	–	–	–	–	–	–	–	–	–	–	–	–
after 48 hours	–	–	Δ	–	–	–	–	–	–	–	–	Δ
after 72 hours	Δ	Δ	ΔΔ	–	–	–	–	–	–	–	–	Δ

Note: Δ; ΔΔ – moderate and strong signs of mold; + – signs of hay bacillus growth

Based on the obtained data, it is obvious that hop and pea-anise sourdough are not only effective in forming the quality of products but also in preventing their microbiological spoilage. Since the optimal conditions for hay bacillus are 37–40 °C and alkaline medium, high acidity of the sourdough as well as the presense of hop and anise antiseptic compounds suppress the activity and reproduction of pathogens. Additionally, the studies have previously established an increase in the antibiotic properties of hop extracts in relation to hay bacillus and mold fungi in acidic medium.

6. Discussion of the results of studying the properties of spontaneous sourdoughs and their impact on bread quality and development of recommendations regarding their use

The efficiency and prospects of using spontaneous wheat sourdough, namely hop, pea-anise, and wine yeast sourdough, to solve the problems associated with improving the quality and expanding the range of bread products have been established. The formulations and parameters of sourdough preparation were selected by analyzing the literary sources and experiences of home bread-baking as well as theoretical foundations of bread technology.

Studying the quality of sourdoughs during their propagation has shown a significant impact of a significant number of factors on the duration of the dilution cycle and their sensory and biotechnological properties. These include the grade and baking properties of wheat flour, the presence of additional ingredients, the cyclicality of replenishment, the methods of preparing the nutrient medium, etc. It was established that wine yeast sourdough acquires the necessary fermentation ability, acidity, and microbial composition the fastest (in 24 hours). The water-flour mixture used in the first mixing was prepared from 1st grade flour that was gelatinized and saccharified. Sourdough propagation with daily introduction of flour, water, and hop water extract into the nutrient medium lasted for 7–8 days. Pea-anise sourdough that includes pea-anise extract requires ripening for at least 15 daily replenishment cycles.

During the specified period, the lifting force of sourdough reaches the recommended values (20–25 minutes). At the same time, the acidity is stabilized at 9.5–10.5°. The sourdough samples made from 1st grade flour, which is associated with a higher content of vitamins, macro- and micronutrients, which are necessary for the reproduction and fermentation activity of the microflora, had the best quality parameters.

The prepared sourdoughs differed slightly by titrated acidity and microbiological composition (the ratio of yeast and lactic acid bacteria). There were general sensory signs of lactic and alcoholic fermentation and specific signs, due to the presence of additional ingredients and their influence on the process of sourdough ripening and the production of aromatic and flavoring compounds.

It has been established that the stability of sourdoughs, that is, the preservation of their properties, in the production cycle is also influenced by their formulation and features of microbiological composition. There were no significant changes in the main properties of hop and pea-anise sourdough for 90 days of propagation. The balance of the nutrient medium composition in sourdough and the correspondence of the selected parameters to the requirements of the fermentative microflora ~~is~~ are indicated by the sufficient amount of lactic acid bacteria and yeast and the presence of both budding and adult cells with glycogen content. This allows to predict the possibility of their continuous propagation for a long time, as long as the sanitary norms and necessary technological parameters are adhered to, as well as systematic control of their quality. Duration of wine yeast sourdough propagation should not exceed 30 days, as afterwards the lifting force is reduced and titrated acidity increases too much. This could be due to the properties of yeast cells and other microflora and their winemaking origin. The importance of additional ingredients for the formation and stability of sourdough quality is evidenced by the rapid loss (after the 8th day) of the lifting force in the control sample, which was replenished with a mixture of flour and water only.

Sourdoughs, according to the results of farinogram analysis, have different effects on the protein-proteinase complex of flour and require different approaches for dough preparation, particularly, its mixing. On the one hand, in all samples the water absorption increases due to deeper swelling of biopolymers. On the other hand, the inclusion of 30 % of hop sourdough to the mass of flour leads to a certain decrease in the elasticity of the dough, a prolongation of its stability and a reduction of dilution during mixing. This is evidently due to the influence of the active substances of hop, their ability to reduce the activity of proteases. The inclusion of the same amount of pea-anise and wine yeast sourdough, on the contrary, led to an increase in dough elasticity, a slight decrease in the duration of its stability, and increased susceptibility to structure destruction and dilution. Changes in dough behavior during mixing were most likely caused by the interaction of gluten proteins with the components of additional ingredients of sourdough (proteins, polyphenols, pectins). Other reasons may be the presence of activators or inhibitors of proteases, as well as features of enzymatic systems of spontaneous microflora.

Investigating the properties of semi-finished and finished products by test baking shows the expediency of preparing dough without yeast using liquid sponge and spontaneous wheat sourdough in the amount of 30 % to the mass of flour. However, the bread was of high quality despite the different dough preparation methods and was not inferior to the corresponding control samples made with pressed yeast. Sensory, physical, and chemical parameters of bread with different sourdoughs differed, primarily by the flavors of taste and aroma, pore structure, coloring of the crumb and crust, and acidity.

The preparation of bread with spontaneous sourdough allows to extend the duration of freshness preservation due to deeper colloidal and biochemical transformations of biopolymers, and their interactions with each other and additional ingredients during prolonged fermentation of semi-finished products. This contributes to a more complete starch gelatinization and protein denaturation during baking, and slows down their aging process during storage. The effectiveness of spontaneous sourdough in prevention of microbiological damage of wheat products, including while processing raw materials with increased microbiological contamination, was established. At the same time, hop and pea-anise sourdoughs were more effective for stabilizing the quality of products during their storage, with wine yeast sourdough samples being slightly inferior.

Thus, national technologies of spontaneous sourdough bread are characterized by a number of peculiarities and specific difficulties. This, despite the undoubted quality advantages of the obtained products, has led to the rejection of their use in the past and impedes their implementation today.

The main difficulties and disadvantages of such technologies are as follows:

1) the limited, unsystematic, and imperfect information in this area in the historical and contemporary contexts, in the context of different regions of the world, in terms of terminology, formulations, and organization of production;

2) the absence of clear requirements for the quality of raw materials, sourdough, semi-finished and finished products, as well as effective control methods;

3) duration, multi-stage, and complexity of preparing spontaneous sourdough and bakery products based on it;

4) poor predictability of the technological process, instability of the sourdough and product quality, the need for constant adjustment of parameters at each stage of preparation due to a significant number of factors;

5) lack of a deep theoretical base and understanding of the scientific fundamentals of spontaneous sourdough bread technology, the essence of complex, interconnected, interdependent processes, the role of prescription components in the formation of the properties of sourdough, dough, and products;

6) imperfection of regulation methods for the technological process and stabilization of the quality formation of semi-finished and finished products;

7) the lack of systematized data regarding the patterns of fermentative microflora development in the dilution and production cycles of various sourdoughs, the speed of obtaining the necessary properties, the transformation mechanisms of biopolymers and other components of dough systems.

Solving these problems is complicated by the large variety of approaches that form the quality of national products. The use of both traditional bread baking methods and methods specific for certain regions or special types of products is a guarantee of their uniqueness. This applies primarily to the content and ratio of raw materials used in recipes, both for sourdough and bread products. Fluctuations in the chemical composition and baking properties of raw materials are related to national and regional features of varieties, climate, soil, and other conditions of growing and preparing them. The application of different conditions, equipment, and production principles in aggregate has a decisive influence on the formation of product quality.

It should also be noted that the requirements for the technology and properties of sourdough from the point of practical implementation according to certain criteria are the same, but to a large extent, significantly vary depending on the type of the enterprise. Portioned dough preparation and use of manual labor prevail in stand-alone mini-bakeries, restaurants, trade and catering enterprises. Industrial bakeries and factories are distinguished by high mechanization degree of operations, continuous processes, and large volumes of production. For example, significant parameter adjustment of the technological process, which is necessary for the formation of the necessary properties of semi-finished products and products, that can be implemented in mini-bakeries, is impossible in highly mechanized enterprises. The use of spontaneous sourdough in most domestic bakeries will only be effective under the additional conditions of maintaining the principles of continuous operation of complex mechanized lines, or it requires the introduction of portioned production.

When choosing raw materials, giving preference to the local resources, it is necessary to establish requirements for their chemical and microbiological composition, safety and technological properties, to formulate criteria for their evaluation, and to create an information base regarding the recommended parameters. It is important to offer comfortable and effective methods of controlling the properties of raw materials, parameters of the technological process, quality formation of sourdough and other semi-finished products, as well as methods for evaluating consumer characteristics, nutritional value, and biological activity of finished products. The latter is relevant to their effectiveness and the ability of the products to conform to the general and specific requirements of their quality, particularly its shape, flavors of taste and aroma, pore structure, crust color, etc.

Thus, it is necessary to clarify and formulate theoretical foundations for the revival of ancient national or ethnic traditions of bread making and their effective practical implementation at domestic enterprises. The development of practical recommendations for spontaneous sourdough bread production will require adaptation to local raw materials and common patterns of production and equipment in the conditions of industrial bakeries and mini-bakeries (Fig. 7).

This requires a combination of efforts of bakers and experts in the field of history, ethnography, agriculture, chemistry, biochemistry, microbiology, nutrition, restaurant management, etc. Only under such conditions it is possible to realize the high potential of sourdough in solving the problems of the industry and the prospects for expanding the range of products. Additionally, popular models of “ancient, ethnic, authentic technologies”, “live”, “artisan” bread, “for health”, “with improved physiological properties” can be represented on the market.

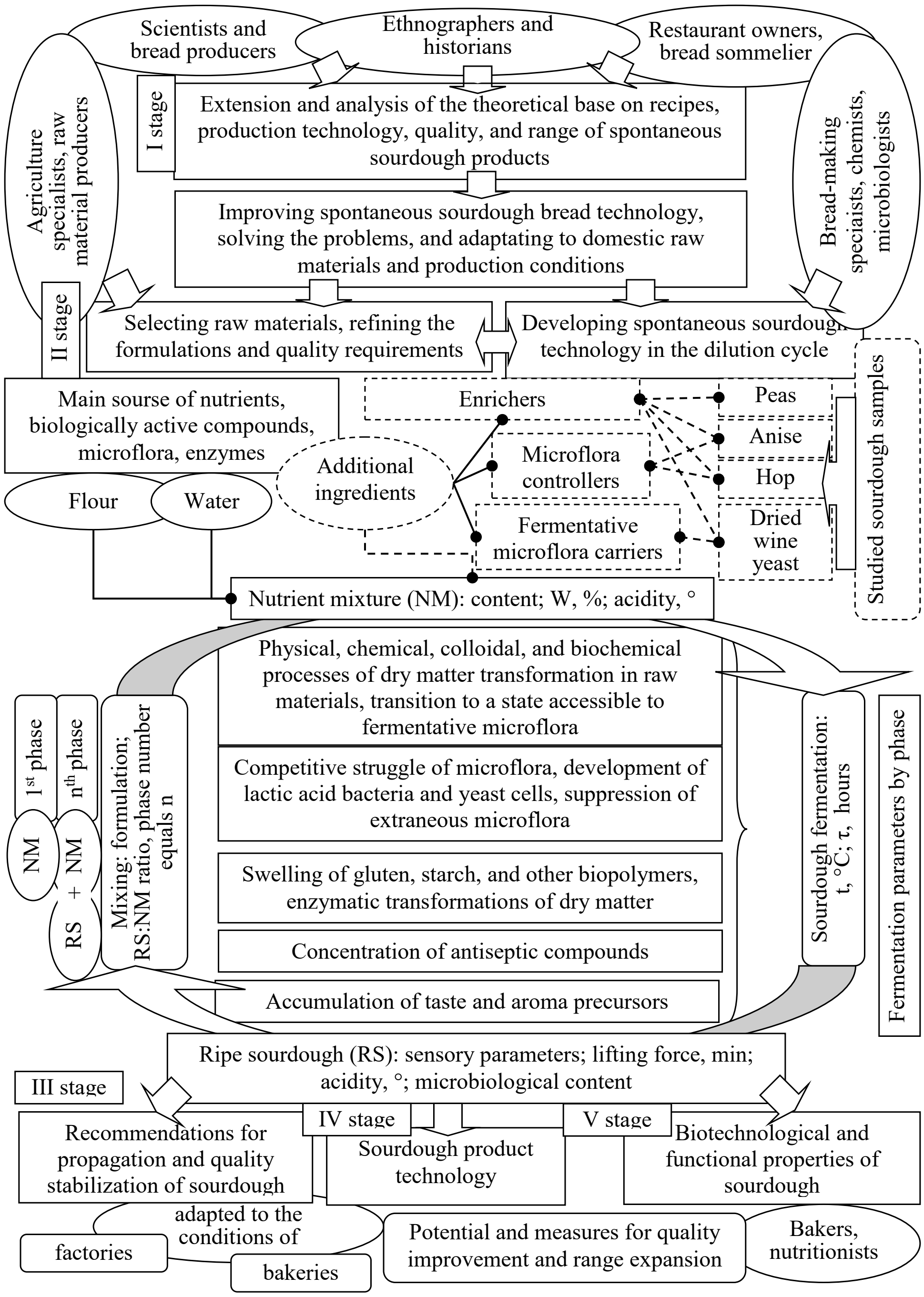


Fig. 7. Stages of forming the theoretical background and practical recommendations for using spontaneous sourdough technologies in bread making

7. Conclusions

1. The speed and features of forming the necessary biotechnological properties of selected spontaneous sourdough in the dilution cycle and the effect of the formulation and nutrient medium preparation have been studied. It has been found that it is advisable to add dried wine yeast in the first phase of the dilution cycle, as well as gelatinize and ferment the water-flour mixture using 1st grade flour. This allows to obtain sourdough with the necessary sensory and microbiological parameters, lifting force, and acidity in 24 hours. Duration of the dilution cycle for sourdough, where each replenishment phase used the same flour, water, and hop water extract is 7–8 days. Pea-anise sourdough, which includes pea and anise extract in the formulation, requires up to 15 days of fermentation. The significant effect of the properties of raw materials, sourdough formulation, and technological methods on the stability of their quality has been confirmed. There were no significant changes in the quality of hop and pea-anise sourdough when they were propagated for 90 days, whereas this period was limited to 30 days for wine yeast sourdough.

2. The ability of spontaneous sourdough to ensure the proper flow of technological processes of dough fermentation and quality formation of bread at the complete exclusion of commercial yeast from the formulation has been established.

Taking into account the established common features and differences in the technological properties of the sourdough, the rational parameters of dough preparation for the selected samples are proposed.

3. It has been established that bread with spontaneous sourdough has good sensory, physical, and chemical characteristics regardless of the method of dough preparation, but the products with liquid sponge had better quality. The bright taste and aroma with a specific flavor and pore structure of bread depended on the features of sourdough formulation and fermentation, and quality. According to the structural and mechanical properties of the crumb, its crumbling and hydrophilic properties, the slower staling of samples with sourdough, primarily hop and pea-anise, has been confirmed. The effectiveness of these sourdoughs for preventing the microbiological damage to products, including while processing raw materials with increased microbiological contamination, was established.

4. Based on the obtained results, it can be argued that these bread-making technologies are extremely promising for the enterprises of bread and restaurant business. Spontaneous sourdough can be considered the means of solving problems and improving bread product quality, expanding its range. However, it is necessary to continue further research with a combination of efforts of different specialists, aimed at elucidation and formulation of the theoretical foundations of spontaneous sourdough bread technology. The development of informative and regulatory base, terms and practical recommendations for manufacturers will require adaptation to local raw materials, common technologies and equipment in the conditions of industrial bakery and mini-bakeries, mechanized and craft production.

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